HEALTH CONSULTATION

Public health evaluation of potential human exposure to FS-28 Plume ethylene dibromide in the groundwater, surface water, and air of the Hatchville area, Massachusetts.

Massachusetts Military Reservation
(a/k/a Otis Air National Guard Base/ Camp Edwards)

Falmouth, Barnstable County, Massachusetts

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Public Health Service
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Table of Contents

Figures

Tables

Purpose

In January 1994 the Agency for Toxic Substances and Disease Registry (ATSDR) released a final public health assessment (pha) for the Massachusetts Military Reservation (MMR; a.k.a. Otis Air Force Base). That pha concluded that site was a "public health hazard" because of the past and current onsite surface soil contamination and onsite and offsite groundwater contamination. Since the release of that pha, the U.S. Air Force, under the direction of the Air Force Center for Environmental Excellence (AFCEE) has collected a large amount of additional environmental data and has further delineated and defined the character and extent of contamination at onsite and offsite locations.

ATSDR prepared this public health consultation in response to community concerns over the off-site Fuel Spill -28 (FS-28) plume of ethylene dibromide (EDB) contaminated groundwater and the potential for past or current human exposure to EDB:

> *(1) in drinking water from wells,*
> *(2) in the Coonamessett River and nearby cranberry bogs, and*
> *(3) in the air near those water bodies.*

Those concerns were raised, in part, by residents of the Hatchville area of Falmouth, Massachusetts, located in close proximity to the areas of potential EDB exposure, and, in part, by residents of the nearby communities of Bourne, Mashpee, and Sandwich, as well as by the Department of Public Health, Commonwealth of Massachusetts.

This evaluation consists of several components: 1) environmental modeling was carried out to help determine past movements of contaminants in the environment, 2) other environmental information about the location and character of EDB in groundwater, surface water and air was gathered, focusing on pertinent information on measured EDB concentrations and potential points of exposure, 3) available air modeling results were reviewed and those estimated values were compared with the collected sampling data, 4) measured or predicted EDB values were compared with relevant health-based screening values, and 5) conclusions were drawn to determine if the level and duration of potential exposure to EDB represent a potential past or present health hazard.

Findings

1. The FS-28 Plume of ethylene-dibromide (EDB) contaminated groundwater has not contaminated private or municipal drinking water wells in the Hatchville, MA area and therefore, those wells do not represent a past, present, or potential future public health hazard.

This finding is supported and further defined by the following facts or conclusions contained in this public health consultation:

a. The FS-28 Plume lies deep within the aquifer and is separated from drinking water wells by about 60-100 feet of clean, uncontaminated drinking water.

b. Groundwater withdrawals by water wells are replenished by lateral groundwater flow to the wellbore. The FS-28 Plume is not drawn up into area wells.

c. Drinking water supplied by the Coonamessett Water Supply Well (CWSW) is safe to drink. This is true for the past, the present, and for the reasonably foreseeable future.

2. EDB contamination in surface water and ambient air of the Hatchville area occurred from about 1983 to May 1999.The highest potential for human exposure to EDB in surface water occurred in the Coonamessett River and adjacent cranberry bogs in the zone between the river crossings of the Hatchville and Thomas B. Landers Roads. The highest potential for EDB exposure in the air also occurred immediately above and in close proximity to the river and bogs in the same area.

This finding is supported and further defined by the following facts or conclusions contained in this public health consultation:

a The earliest arrival date for the FS-28 Plume at the upwelling zone (at very low levels) is probably no earlier than 1983.

b. The zone of upwelling groundwater in the valley of the Coonamessett River, between Hatchville and Thomas Landers Roads, defines the northernmost point of potential human exposure to EDB in surface water and air.

c. The last detection of EDB in surface water was in May 1999. Based upon the remediation measures in place, the potential for human exposure to EDB in the surface water and air pathways ended no later than that date.

d. From 1983 to mid-1999 (16 years) the FS-28 Plume discharged EDB to surface waters resulting in maximum observed concentrations of 0.73 ppb or less in area

surface waters.

e. The segment of the Coonamessett River and adjacent cranberry bogs located between the Hatchville and Thomas B. Landers Roads comprise the only segment of that surface water environment that was, from possibly as early as 1983 to mid-1999, a potential (past) pathway of human exposure to EDB.

f. The maximum levels of airborne EDB probably did not exceed 0.01 ppb throughout the potential human exposure period from 1983 to mid-1999.

3. A conservative analysis of the potential past exposure to EDB contamination in surface water and air of the cranberry bogs area near the upwelling zone of the FS-28 Plume shows that no adverse human health effects should arise from this low-level exposure to EDB. In downstream locations below Thomas B. Landers Road, EDB contamination levels are progressively lower, and therefore, the potential for adverse human health effects is lower as well. Accordingly, there does not appear to be the need for follow-up health activities regarding EDB exposure in the Hatchville, MA area.

This finding is supported and further defined by the following facts or conclusions contained in this public health consultation:

a. The estimated exposure levels to workers from breathing EDB in air, from incidental ingestion or skin contact with contaminated surface water were lower than levels at which adverse health effects have been shown to occur.

b. The total combined exposure estimate for the cranberry workers (9.8×10^{-7} mg/kg/day) was 58 times lower than the EPA provisional inhalation reference dose.

c. ATSDR considers that the levels of exposure to EDB for cranberry workers were below a level of concern for cancer effects.

Background

The area now known as the Massachusetts Military Reservation (MMR) is located in the western portion of Cape Cod and covers an area of about 34 square miles (Fig. 1). MMR was originally established in 1912 as Camp Edwards, a U.S. Army training facility. In 1940, the 101st Observation Squadron, Massachusetts National Guard was inducted into federal service and moved from Logan Airport to Otis Field at Camp Edwards. At the conclusion of WWII, on October 15, 1946, the 102nd Fighter Group with the 101st as its assigned fighter squadron was organized. It became the first Air National Guard unit to conduct postwar training at what was then called the Otis Air Base.

The heaviest military activity at the installation was from 1940 to 1946 and from 1955 to 1972. The use of petroleum fuel products and industrial solvents peaked during those intervals, as was the generation of hazardous waste materials. The customary waste disposal activities at that time included disposal of such wastes in landfills, in dry wells, and for use in firefighter training areas. These disposal practices permitted contaminants to infiltrate down through the surface soils and underlying, unsaturated sand, silty-sand, and gravel deposits (30 to 60 feet thick) to the water table. When these fuel and solvent products reached the top of the water table they merged with the groundwater to form dissolved plumes of organic contaminants. The contaminant plumes that were created from several source areas on the MMR installation began to migrate laterally with the groundwater that is flowing radially outward from the installation. With an average groundwater flow rate of about 1 to locally as much as 2 feet per day, some plumes of contaminated groundwater have extended beyond the MMR boundary to distances of more than four miles (Fig. 2A).

MMR is located on the top of the recharge area for the sole-source aquifer (known as the Sagamore Lense) from which the nearby towns draw their municipal drinking water. Numerous shallow private drinking water and irrigation wells are also drilled in this alluvial aquifer.

In December 1992, ethylene dibromide (EDB or 1,2-Dibromoethane) was discovered at a level of 0.05 ppb in a monitoring well (MW-1206Z) installed near the leading edge of the Chemical Spill No. 4 (CS-4) plume south of MMR. Since that time there have been numerous investigations to delineate the character and extent of EDB south of the CS-4 extraction fence. The EDB plume of contamination thus delineated was designated the Fuel Spill No. 28 (FS-28) plume in November 1996 (AFCEE, 1999a: see Fig. 2A).

Although there are about 80 potential source areas identified on MMR (AFCEE, 1999a; see Fig. 2B), a review of historical usage of those potential source areas and the area's hydrogeology limits the number of potential sources for the FS-28 Plume to about four or five likely sites. However, the FS-28 plume is detached from its source(s) and the investigations conducted thus far have not identified and are not likely to identify the specific source area(s).

Discussion

Site Description

$ Geography and Geology

The area of concern of this public health consultation lies within an area described as the Mashpee Pitted Plain (MPP); a glacial outwash plain formed by meltwater flows from the retreating Laurentide Ice Sheet. Deglaciation of the Cape Cod area began perhaps about 18,000 years ago and the area was ice-free by about 14,000 years ago. The surface of the MPP is characterized in some locations by relatively level land such as that found in the Crane Wildlife Management Area north of Route 151, while south of Route 151, isolated closed depressions (kettles) dot the surface and hummocky topography and scattered ponds predominate.

The surface of the MMP is underlain by poorly-graded, stratified sands with many discontinuous silty-sand layers down to about -70 feet mean sea level (msl) in the northern portion of the area and to about -110 to -140 feet msl in the south. Below those depths greater grain-size heterogeneity exists with interbedded silt beds, silt lenses, discontinuous silty sands, and silty-clayey sands (AFCEE, 1999a). These glacial outwash deposits rest upon crystalline bedrock which generally slopes southeastward from about -140 to -220 feet msl. For a more detailed discussion of the area geology the reader is directed to the Southwest Operable Unit Remedial Investigation (AFCEE, 1999a) and the references cited therein.

$ Land Use and Population Growth

The predominate current land uses of the area south of MMR are shown on Figure 3. Of interest to the focus of this health consultation are the areas shown as Residential Areas and Agricultural Areas near the southwestern corner of Coonamessett Pond and south along the Coonamessett River as those areas overlie, are near, or down-river from the FS-28 plume.

A review of aerial photography of the area for the years 1955, 1966, and 1977 shows a pattern of gradual land use change, which by 1977 shows a greater conversion of open space and agricultural lands to residential and other developed uses than in the time intervals described by earlier photos.

Population data for the 1960 - 1990 interval was gathered for the Hatchville area in the general area overlying the FS-28 Plume. The oldest data, from the 1960 and 1970 census compilations, was gathered in Enumeration Districts (EDs) which differed from census to census and from the census-block units used in the later census compilations. Thus, because the boundaries of the counting units have varied over time, the census data are not directly comparable. However, the EDs data can be aggregated together to show the total population for Falmouth, MA which rose from 13,037 in 1960, to 15,594 in 1970, to 22,640 in 1980 and 27,554 in 1990; increases of 19.6%, 45.2%, and 21.7% respectively per decade.

An alternative approach to describing the historical population trends in the Hatchville area is to review the dates that subdivisions were approved by the local authorities. To focus this approach, a potential EDB exposure zone was described by a boundary drawn 300 feet outside of the area described by the triangular system of roads created by the Hatchville, Sandwich, and Turner roads (see Fig. 4). In this zone of potential human exposure to EDB, subdivision approval dates for lands flanking the Coonamessett River range from as early as 1959 (Decosta Circle area, east of the river), to 1988 (Hunkey Dory Farm Road, east of the river), to 1995 (lots on Thomas B. Landers Road, east of the river), to as recent as 1996 (lots near the northern intersection of Turner and Thomas B. Landers roads, west of the river).

Apart from those early and late subdivision approvals, the bulk of the subdivision approval dates and, therefore, the earliest dates for the bulk of new home construction in this zone of potential exposure range from 1962 - 1973 east of the river and from 1963 -1968 west of the river. Although this approach yields only a qualitative indication of the increase of housing and population growth in the area, the data suggest that many families began to establish their residences along this stretch of the Coonamessett River in 1966 to 1968.

A review of the 1977 air photography covering the zone of potential human exposure (Fig. 4) reveals that there were, at that time, a total of 28 homes east of the river (12 homes inside and 16 homes outside the roads used to delineate this area) and 35 homes west of the river (22 inside and 13 outside the roads). The 1980 Census recorded an average of 2.62 persons per household and thus, in 1977 in the zone of potential exposure to EDB it is estimated that about 73 people lived east of the river and 92 people lived to the west of the river. Of that estimated total of 165 people, a total of about 89 people may have lived within the road perimeter used to describe this zone.

Using the 1990 Census data as a basis to estimate the number of residents within the potential EDB exposure zone yields a total of 160 persons residing within that area in 1990. Of that total, there were 14 children, 6 years and younger, and 36 females of potential childbearing age (15 - 44 years).

Because of the general agreement between the 1990 Census data and the estimate based on the 1977 air photography, for the purpose of this Consultation, ATSDR will use the population estimate based on the 1990 Census as an estimate of the maximum number of residents of the zone of potential human exposure.

Site Hydrology

$ Groundwater

Groundwater moves in response to gravity or, in other words, the hydraulic gradient from areas

of high head to areas of low head (generally, from areas of high elevations to areas of low elevation). Figure 5 shows the general configuration of the top of the zone of saturation (contour lines showing the elevation of the water table) and the general directions of groundwater flow.

In addition to differences in head, groundwater flow is in response to the long-term balance between recharge and discharge. Natural recharge to the Cape Cod aquifer (the Sagamore Lense) comes from precipitation which averages about 40-inches annually. Of that 40-inches of precipitation, about 25 inches per year infiltrates through the soil and glacial outwash deposits to join the groundwater (AFCEE, 1999a). The remainder of the annual precipitation is lost to evapotranspiration and runoff. Additional recharge to groundwater occurs along reaches of the Coonamessett River that lose water to the river bed and banks (a losing reach) and locally from the downgradient portion of ponds. Groundwater discharge occurs to the Atlantic Ocean and to coastal locations and to inlets such as Great Pond. More specifically, groundwater discharge occurs to the Coonamessett River (a gaining stream reach), nearby wetlands, and bogs at locations where the hydraulic gradient is toward the river. An upward-directed groundwater flow gradient south of Coonamessett Pond is responsible for the upwelling of deep groundwater and EDB (the FS-28 Plume) into the Coonamessett River and adjacent cranberry bogs (Figs. 4 and 6)

$ Coonamessett Pond and River Hydrologic System

The Coonamessett River flows directly southward from its origin along the west arm of Coonamessett Pond. The pond itself is relatively shallow, attaining a maximum depth of about 34 feet in the eastern half and about 10 feet in the western arm area (Foster, Lauren, 1999, Personal communication). The river passes beneath Hatchville Road, Thomas Landers Road, Sandwich Road, and Route 28. Immediately south of Route 28, the river discharges into Great Pond, a two-mile long estuary. Five miles south of its source at Coonamessett Pond, the water of the Coonamessett River discharges into the Atlantic Ocean at the southern end of Great Pond (Trobridge, 1997).

From the Coonamessett Pond to Hatchville Road the river maintains relatively low flows throughout the year (0.47 to 6.68 cfs). Between Hatchville and Thomas Landers Roads the river gains significant flow from groundwater discharges to the river (a mean increase of 3.9 cfs). It is particularly in the northern part of this stream reach that the upwelling of the FS-28 plume occurs (AFCEE, 1999a).

EDB contamination has not been detected in Coonamessett Pond, but as we will discuss in greater detail in later sections of this report, EDB contamination has been detected in the Coonamessett River and in adjacent cranberry bogs affected by the upwelling FS-28 Plume.

The FS-28 Groundwater Plume

$ Source, Character, and Extent

Plume Source

EDB was first produced in 1923 and was added to leaded gasoline, including aviation gas, as a lead scavenger. However, there is no specific indication when the practice was first initiated on a widespread basis. Beginning sometime in the 1920's and continuing till 1970, the concentration of the EDB additive in fuels reported ranged from 200 to 280 ppm in leaded fuels (AFCEE, 1999a).

The recorded history of the 102nd Fighter Wing, Otis ANGB states that fixed wing aircraft were first stationed at MMR in 1940. No records have been found to indicate that EDB was ever stored in its pure form or to indicate that it was ever applied as a soil fumigant[1], so it is likely that EDB was released to the environment in fuel spills or leaks (AFCEE, 1999a). Thus, the probable source areas of EDB contamination in groundwater are those sites on MMR that were used for fuel storage or transfer. Based upon a review of site history and subsequent sampling, several possible sources on MMR have been identified. Those sites include such sites as the CS-10, CS-4, FS-2, FS-9, FS-19, and USCG CS-3 areas (AFCEE, 1998, 1999, GeoHydro, 1998) and are shown on Figure 2B.

Of the potential source areas of EDB identified, the closest source area to the FS-28 Plume is FS-2, a railroad fuel pumping station located at the southeast boundary of the MMR golf course in a former railroad yard at the southern end of Guenther Road. At FS-2, fuel transferred from 10,000-gallon railroad cars to a 10-inch underground pipeline that carried AVGAS or JP-4 to aboveground storage tanks. Of the other sites investigated, perhaps the strongest evidence of EDB contamination is found at the CS-10 site; the most-distant site from the FS-28 Plume and located at what was known until 1978 as the BOMARC site and subsequently as the Unit Training Equipment Support area. At this site, fuels and solvents were used extensively.

Based upon ATSDR's review of the site history and the history of spills or releases at potential source areas, **the most probable period of release to EDB to the environment was during 1940-1945, the WWII war-years period of peak activity at the installation**, and from 1955 to 1972. Spills or leaks at other times certainly may have contributed to the observed contamination in the plume. It should also be noted that other off-base sources of EDB usage or fuel spills may have contributed to the present day observed contamination in the FS-28 Plume.

It is likely that several source area sites, at different times, contributed to what now comprises

[1] In the 1970's and early 1980's EDB was used in soil to kill insects and worms that get on fruits, vegetables, and grain crops. It was also used to protect grass, such as on golf courses. Another use was to kill fruit flies on citrus fruits, mangos, and papayas after they were picked. The EPA discontinued most of those uses in 1984.

the FS-28 Plume. **Because the FS-2 source area is the closest to the southern boundary of the installation and, in turn, to the Hatchville area, this analysis will focus on contaminant release from that site, because EDB released from that site would be the first to arrive at areas of potential human exposure.**

Environmental fate and transport

In groundwater, EDB is persistent when compared to the hydrocarbon components of gasoline because it is relatively resistant to microbial degradation.

At MMR, EDB has migrated significantly from its source. Since seeping into the soil, the compound has migrated to groundwater, surface water, and air. As EDB has traveled, however, the concentration of the compound has been reduced by a variety of physical and chemical processes. In the discussion that follows, ATSDR describes the chemical, physical, and biological processes that control the transport and fate of EDB in different environmental media and factors influencing its degradation.

EDB in Soils

Most of the EDB that is released to soils does not remain in this medium for long durations because:

a. *EDB has a low sorption potential and it dissolves readily in water.* The likelihood that a chemical will remain adsorbed, or adhered, to soil can be predicted by its organic carbon partition coefficient (K_{oc}). K_{oc} values can range from 1 to 10^7 milliliters per gram (mL/g). Lower values indicate a lower tendency to adhere to soil and higher values indicate a greater tendency to adhere to soil. EDB, with a K_{oc} reported between 36 and 162, is considered to have a low sorption potential, meaning that the surrounding soils do not have a strong "hold" on the contaminant (ATSDR, 1992; GeoHydro, 1998). In addition, EDB has a high water solubility, meaning that it dissolves easily in water. Solubility measurements for common organic compounds range from below 1 ppm (low solubility) to 1,000,000 ppm (high solubility). EDB, with a solubility ranging from 2,910 ppm to 4,321 ppm, is considered to be readily soluble (GeoHydro, 1998). EDB's low sorption potential and solubility in water indicates that it will likely pass through soil and become dissolved in the underlying aquifer.

b. *EDB tends to volatilize readily.* A chemical's vapor pressure describes how easily it can volatilize into the atmosphere from dry soil. A contaminant with a vapor pressure of less than 10^{-6} millimeters of mercury (mm Hg) tends to remain in soil; above 10^{-6} mm Hg, the contaminant tends to volatilize into the atmosphere. EDB, with a vapor pressure of about 11^{-6} mm Hg, has the ability to volatilize readily (ATSDR, 1992). Some studies show that 20 percent of EDB volatilizes within two days when the chemical is applied as a soil fumigant at a depth of 15 centimeters (GeoHydro, 1998). At MMR, however, the

chemical was not applied in this fashion. Rather, it was component of fuel spills. Because EDB was released in such a fashion and because the chemical has such a high solubility, investigators do not think that much of the EDB escaped from the soil into the atmosphere (GeoHydro, 1998).

c. *EDB breaks down into other chemical forms*. In aerobic surface soils, EDB has been shown to biodegrade to a limited degree. However, it is relatively resistant to microbial degradation (ATSDR, 1992). Biodegradation is a biological process that involves converting a chemical into a new form via interactions with organisms, such as bacteria or fungi.

Although most of the EDB that is released to soil migrates readily to groundwater, some small fraction does remain strongly sorbed to soil micropores (ATSDR, 1992). Investigators have found that this residual is extremely immobile and resistant to degradation. As a result, levels of EDB can persist in soils for several years, with very small quantities of EDB leaching to underlying aquifers over time.

<u>EDB in Groundwater</u>

EDB persists in groundwater for long durations. The environmental fate of EDB in groundwater is persistent when compared to the hydrocarbon components of fuels because it is relatively resistant to microbial degradation. After entering groundwater, the migration route of EDB is determined primarily by the geological formations that exist in the subsurface. At MMR, EDB flows along groundwater pathways to discharge zones along the Coonamessett River (AFCEE, 1999a). As the groundwater flows further from the contaminant's source area, concentrations decrease as a result of several physical processes:

a. *Molecular Diffusion*. This process describes the random motion of chemical molecules from areas of high concentration to areas of low concentration. An example of molecular diffusion would be dripping red food color into a bowl of still water. Initially, there would be a small area with a deep red color, over time, however, all the water in the bowl would become an even pink color.
b. *Turbulent Diffusion*. This process describes the random motion of the air or water containing a chemical to move the chemical from areas of high concentration to low concentration. An example of turbulent diffusion would be dripping red food color into a bowl of still water and then stirring it. All the water in the bowl would quickly become an even pink color. Turbulent diffusion occurs, to a limited extent, in groundwater as water flows through pores and fractures in an aquifer and, to a much greater extent, in streams and rivers as water flows downstream.
c. *Hydrodynamic Dispersion*. This process describes the spreading of the chemical in the groundwater caused by the fact that not all the chemical moves at the same speed as the average linear velocity of groundwater. Deviations from the average linear groundwater velocity are caused by local heterogeneities such as grain size and pore shape or

orientation.

d. *Retardation.* This process describes the adsorption of chemicals to the aquifer matrix (e.g., particle surfaces). For a given mass of a dissolved chemical, the fraction available to be transported by groundwater flow is influenced by the adsorptive properties of the aquifer matrix. Commonly, the organic carbon and very fine, colloidal-sized particle content of the aquifer play an important role in determining the relative retardation of many chemical contaminants. EDB transport in groundwater may be little affected by retardation while the associated fuels were retarded and degraded before reaching the Hatchville area (AFCEE, 1999a).

Depending upon the depth to groundwater, volatilization can also play a varying role in decreasing EDB concentrations. In shallow aquifers, for example, investigators have found that EDB volatilizes into the vadose zone (non-saturated zone above aquifer) at a moderate rate. The chemical is able to do so because it has a Henry's Law Constant in the 10^{-4} range. (Henry's Law Constant describes how easily a contaminant will volatilize to the atmosphere when it is in water or wet soil.) Contaminants with a Henry's Law Constant higher than 10^{-3} atmospheres per cubic meter per mole (atm-m^3/mole) are expected to easily volatilize; from 10^{-3} to 10^{-5} atm-m^3/mole are expected to have moderate volatilization; and below 10^{-5} atm-m^3/mole are not expected to volatilize from water or wet soil. Therefore, it is unlikely that much EDB has volatilized from the groundwater at the MMR site, because, except for the zone of upwelling groundwater in the Coonamessett River and bog area, **the EDB is located deep within the aquifer, away from the vadose zone** (AFCEE, 1999a).

Biological and chemical reactions can also play a role in decreasing EDB concentrations in groundwater. In laboratory studies, EDB has been shown to degrade via biodegradation and hydrolysis. As stated before, biodegradation is a biological process. Hydrolysis is an abiotic process that occurs when chemicals interact with water to form new chemical species. The half-lives (or the time required to reduce a contaminant concentration by half) of these degradation processes have been measured in laboratory experiments. Studies involving the chemical hydrolysis of EDB show that half-lives range from 1.5 to 15 years (GeoHydro, 1998). The half-lives reported in studies that focused on microbial degradation were much shorter (i.e., 35 to 350 days), but were shown to extend for longer periods as the initial concentrations of EDB increased (GeoHydro, 1998). Although these laboratory studies provide interesting information, it should be remembered that conditions in the field are often quite different from those that are in laboratories. These field conditions, for example pH and oxygen content, strongly influence the rate of hydrolytic and biodegradative reactions. At MMR, hydrolysis is suspected to play a more important role than biodegradation in degrading EDB in groundwater (AFCEE, 1999a). In one study, investigators estimated that the half-life for EDB in the MMR subsurface ranged from about 5.5 to 13.7 years (GeoHydro, 1998).

Compared to EDB, hydrocarbon fuels are easily degraded and relatively immobile, which may explain why after about 40 or 50 years, EDB appears to be the only fuel-related component still found in FS-28 Plume downgradient from MMR.

Plume Character and Extent

The current location of the FS-28 Plume is shown in map view in Figure 4 and in cross-sectional view in Figure 6. The FS-28 Plume is a detached plume, meaning that clean, uncontaminated water exists between the plume and potential source areas. The source area or areas have not been identified. As previously discussed, of the potential source areas identified, the closest source area to the FS-28 Plume is the FS-2 site.

The plume extends from the Crane Wildlife Management Area, below the western arm of the Coonamessett Pond, and terminates in the Coonamessett River and cranberry bogs area just north of the Thomas B. Landers Road near the river crossing. As presently configured, the plume's northern boundary is defined, as is the plume boundary elsewhere, by monitoring well data that does not detect (ND) the presence of EDB at depth.

As shown on Figure 6, the FS-28 plume lies deep below both the land surface and the water table. In the extreme northern portion of the plume, in the vicinity of Highway 151, the plume lies about 100 feet below the land surface and 70 feet below the top of the water table. Progressing to the south along the line of cross-section, the depth to the top of the EDB plume generally declines from 100 to 130 feet below the land surface and from 70 to 125 feet below the top of the water table (AFCEE, 1998). Beyond the location of the extraction well installed to control and remediate the EDB plume and the Hatchville Road, the plume rises toward the surface to discharge to the Coonamessette River and nearby cranberry bogs (see Figs. 4 and 6).

An extraction well and associated granular activated-carbon (GAC) treatment plant were placed in service October 14, 1997. Since that time most of the plume at this location has been captured, treated, and discharged to the Coonamessett River in the area of greatest groundwater discharge to further limit plume upwelling and migration (AFCEE, 1999a, 1999b). In October 1997, to augment the remediation efficiency of the extraction well and separate the Coonamessett River and bogs from EDB contamination, the Air Force initiated construction of a system of numerous well-point (small diameter, shallow) extraction wells in the groundwater upwelling zone and the construction of earthen berms and sheet pilings to ensure separation of the bogs and the river (AFCEE, 1999a). The apparent efficiency of these combined remediation measures is documented by the fact that **EDB has not been detected in surface water since the monthly sampling round conducted in May 1999.**

The plume has migrated to its present position by advective transport with the groundwater. The highest concentration of EDB measured in the FS-28 Plume is 18 ppb at a depth of about 212 feet below the surface (-180 msl), deep within the core of the plume and about 50 feet above the underlying bedrock. The sample containing 18 ppb EDB was collected from a monitoring well near the location of the extraction well drilled south of the Hatchville Road. Concentrations of EDB within the plume decrease to both the north and south of that extraction well site. A small

portion of the plume lies downgradient, beyond the current and proposed additional extraction systems, and will eventually discharge into the Coonamessett River in very low to nondetectable concentrations.

At present and probably since the first arrival of the FS-28 plume terminus at its present location north of Thomas B. Landers Road, the extent and character of the plume is limited by several factors:

a. First, the hydrogeologic factors that result in the localized upwelling and discharge of groundwater to the Coonamessett River and adjacent cranberry bogs, have apparently greatly limited further downgradient migration of the plume.
b. Second, the highest concentrations of EDB found within the plume are localized in deep, fine-grained sediments. Those finer-grained sediments retard contaminant migration. It appears that, through dispersion and advective flow, groundwater flow through adjacent, more permeable zones is transporting lower-concentrations of the EDB plume to the surface.
c. Third, the practice of flooding the cranberry bogs at various times of the year may have retarded or created an intermittent groundwater barrier to southerly plume migration.
d. Fourth, since October 1997, pumping of the extraction well has removed much of the remaining EDB in the plume and further limited plume migration.
e. Finally, the practice of discharging the treated water from the extraction well to the river and bogs may retard or dilute the discharge of EDB to surface

$ Drinking Water Wells and Contamination

Municipal Drinking Water

Falmouth's Coonamessett Water Supply Well (CWSW) is located about 500 feet south of the west arm of the Coonamessett Pond within the area currently underlain by the FS-28 Plume. The CWSW has a bottom depth of about 60 feet bgs and has a 10-foot screened interval at the bottom of the wellbore. Although **EDB contamination has not been detected above detection limits in the CWSW**, as a precautionary measure that well was equipped with a granular activated-carbon (GAC) filtration system at the wellhead (AFCEE, 1999a). That GAC system went into operation during July 1996.

In order to more fully evaluate the potential for the CWSW to be contaminated by the underlying FS-28 Plume (about 65 feet below the bottom of the CWSW), a 1 million gallons per day, 72-hour pump test was conducted on that well in May 1996. The results of that pump test, demonstrated that the well recharge is not drawn up from levels below the wellbore, but rather is from lateral groundwater flow. Most of the well recharge comes from the western arm of

Coonamessett Pond (GeoHydro, 1998). **Thus, it is highly unlikely that the CWSW has been or will be influenced by EDB in the FS-28 Plume**. Samples are collected monthly from nearby sentinel monitoring wells and from raw, untreated water from the CWSW **to ensure that the municipal water is and will continue to be safe to drink.**

Private Drinking Water Wells

Since October 1996, private drinking water wells have been tested to detect possible contamination. Since that time approximately 840 samples have been collected. Sampling of 339 individual water wells was conducted on a biweekly or, in some cases, longer intervals for a period ranging from a few months to more than two years. This sampling resulted in a total of three detections of EDB (detection limit 0.006 ppb). At the first residence, the two detections (0.0084 and 0.17 ppb) of EDB were isolated "hits" or detections in a biweekly testing series of samples collected over a 2.25 year period. The samples collected immediately before and for two sampling events (one month) after the "hits" did not confirm the presence of EDB. Similarly, the single "hit" of 0.059 ppb EDB detected at the second residence was not confirmed by the other samples collected during a 12-month period. The reliability or validity of isolated detections of this sort are highly questionable. It is very possible that these detections resulted from sampling error, sample contamination, or laboratory error. Regardless of the question of the validity of these samples, the samples represent a potential human exposure duration of only 14 to 28 days. As discussed later in this report, current epidemiologic, toxicologic, and medical information indicates adverse health effects are unlikely from exposure at these low levels and short durations.
Because the FS-28 Plume lies deep within the aquifer, well below the depths penetrated by the area's private wells, it is unlikely that those wells have been contaminated by EDB in the past.

$ Groundwater Modeling of the FS-28 Plume

General Considerations

Mathematic models, used commonly in groundwater studies, are an attempt to represent physical, chemical, and biochemical processes by mathematical equations. These models may be 1-, 2-, or 3-dimensional representations or approximations of reality. The time-dependent progression of physical or chemical processes over time is frequently an attribute of such models. Models applied to the solution of a problem can be either generic or site-specific. Site-specific models attempt to incorporate more of the local site characteristics and, therefore, are usually more accurate representations of the real site conditions.

Naturally, the starting point for modeling efforts is a clear understanding of the processes involved. Groundwater flow, considered by itself, is controlled by two dominant processes: flow

in response to hydraulic potential gradients and the gain or loss of water in the groundwater system being studied. In the case of contaminant transport, a much larger number of diverse and complicated processes are involved. These processes can be divided into two broad categories: those processes responsible for fluxes (e.g., advection, diffusion, mechanical dispersion) and those responsible for sources or sinks for the contaminant (e.g., sorption, hydrolysis, biodegradation). In addition to those processes that can be thought of as physical or chemical laws or principles, the hydrogeologic character of the deposits (e.g., horizontal or vertical anisotropy due to stratification, grain-size variation, fractures) through which the fluid must pass must also be integrated into the model. **The degree to which all the controlling variables and parameters are known determines the certainty or precision of the modeling results.**

Groundwater models can be used with varying degrees of success to better understand or describe existing groundwater flow systems by permitting extrapolation of a relatively small set of data into a more comprehensive description of the whole system. In this case, existing data are being used to predict the character of the existing system at locations where data have not been collected. The predictive character of a groundwater model can also be used to evaluate changes in the groundwater system, such as contaminant migration, with the passage of time. Thus, a groundwater model can be used to predict the potential past or future location or configuration of a groundwater plume. The accuracy of such model predictions frequently decreases with increasing distance or time from the known present conditions.

Several problems are presented when attempting to create a groundwater model to predict or, if you will, reconstruct the migration of the FS-28 Plume of EDB-contaminated groundwater in the Hatchville area south of MMR. These problems include the following:

a. **The specific source area(s) are not known.**

Although (1) historical documentation is available to indicate which areas at MMR handled, stored, used, or disposed of fuel products, (2) sampling data discloses the presence of EDB at some potential source areas, and (3) hydrogeologic evidence has been compiled to indicate which source potential areas would result in plumes migrating toward the Hatchville - Coonamessett Pond area, the specific source area(s) will probably remain unknown.

b. **The plume migration distance(s) are variables.**

Because the specific source area is not known, the migration distance from the source to the present plume terminus is also unknown. Contaminant migration distance is an important variable in determining plume migration time.

c. **The date(s) of EDB-containing fuel spill or release are not known with certainty.**

The compiled site histories of potential source areas points strongly to spills or releases occurring in the 1940-45 time-period, but a specific event or events and dates have not been identified.

d. **The spill or release volume(s) or concentration(s) are also unknown.**

Did EDB seep into the groundwater as a result of a single event or multiple events?

e. **The depth from the surface to the watertable at the source area is not known.**

Because the source area(s) are not known with certainty, the depth from the surface down to the watertable is also unknown. The infiltration rate of contaminants down through the unsaturated vadose zone to the groundwater is typically much slower than the linear flow rate of groundwater. Thus, the time necessary for contaminants to infiltrate to a shallow depth can be considerably different than the time required to infiltrate to greater depths. The concentration of the contaminants reaching the watertable can also be affected.

f. **Vertical and horizontal anisotropy of the aquifer is difficult to accurately characterize.**

Glacial outwash deposits typically show complex, braided-patterns of grain-size and sorting variations and thus, permeability variations in both the horizontal and vertical dimensions. A large number of subsurface borings and other geophysical data are necessary to characterize such deposits. Even given detailed site characterization, modeling of such anisotropy is very difficult and, in reality, groundwater migration rates may be largely dependent on the relative volume and permeability of the coarser grain-sized sedimentary deposits.

g. **Climatic variation and human influence can significantly alter the groundwater model variables.**

Variation in annual precipitation quantity and intensity can alter infiltration rate or groundwater recharge volume. Similarly, changes of land use or soil disturbing activities, depending upon the relative percentage of the recharge area involved, can also affect infiltration and/or total groundwater recharge.

The FS-28 Groundwater Pathway Analysis

Given the above generalized limitations, it should be clear that the task of determining the potential date and concentration of the first arrival of contamination at a point of potential human exposure, regardless of the method or model applied, is subject to some error. For that reason, ATSDR decided to compare the results obtained from a relatively straightforward estimate of the first arrival date compiled from data gathered prior to and during the preparation of the Southwest Operable Unit Remedial Investigation (AFCEE, 1999a) report with the groundwater modeling analysis requested by ATSDR and completed by GeoHydro Systems Management, Inc. (GeoHydro, 1998). A discussion of those approaches follows.

The groundwater pathway analysis for the FS-28 Plume of groundwater contamination should be considered in two stages: (1) the migration of the spilled fuels containing the EDB additive down through the unsaturated zone (the vadose zone) to the water table, and (2) the horizontal migration of the EDB-contaminated groundwater plume in the saturated groundwater zone from the point beneath the source area to the present southern limit of the plume or to a point of groundwater discharge to the surface.

The two site-specific, analytic approaches considered in this section of the consultation are based upon essentially the same set or range of hydrogeologic data amassed during numerous investigations of the area (see AFCEE, 1999a). Both approaches use the 1940 -1945 interval as the most probable date for the initial release or spill of the fuel containing the EDB now detected in the FS-28 Plume.

Groundwater flow-rate estimates of plume arrival dates

The first approach employed by ATSDR to estimate the initial arrival of the FS-28 Plume in the Hatchville area is based upon the wealth of subsurface data, collected for AFCEE by Jacobs Engineering, which describe the porosity, hydraulic conductivity, and horizontal gradient of the alluvial aquifer deposits which permit calculation of the groundwater flow velocities. Based upon our review of these data, **an average groundwater flow velocity of 1 ft/day** was selected as representative of the broad range of groundwater flow conditions within these glacial outwash deposits. While groundwater flow velocities as low as 0.003 ft/day (low gradient and conductivity) to as high as 6 ft/day (high gradient and conductivity) can be calculated, these extreme values are not representative of the local hydrogeologic setting because steep gradients are usually associated with low hydraulic conductivities and lower gradients are associated with higher hydraulic conductivities. AFCEE (1997) reports average linear groundwater flow velocities from 0.02 to 0.2 ft/day for silty sands and 0.2 to 2.0 ft/day for the coarser-grained outwash deposits. These values are consistent with the 1 ft/day average velocity selected by ATSDR for the aquifer.

This estimate of average groundwater flow velocity must be supplemented with an estimate of the rate and therefore, the time of infiltration of water and EDB down through the vadose zone. The analytical method reviewed by ATSDR that has been applied to estimate this travel time is the Marino Model incorporated in the ACTS software used at this site by GeoHydro Systems Management, Inc. (GeoHydro, 1998). Estimates obtained by this one-dimensional model suggest that there is a 20 percent probability to exceed 70 percent of the surface spill or release concentration of EDB at a depth of 20 ft after five years and a 1.26 percent probability that the same concentration would reach a depth of 30 ft in five years.

The depth to the water table below the FS-2 site is approximately 55 ft which implies that a longer travel time down to the water table must be required for a 70 percent concentration of the contaminant release at the surface. However, because we do not know the specific details of the timing, duration, and concentration of the spill or release, the 5-year infiltration time was chosen as the minimum time of travel and therefore, the time value that would result in the earliest potential arrival time of EDB in the Hatchville area. Although this 5-year infiltration time under-estimates the probable true arrival time of contaminants at the water table, it errs on the side of protecting the public health by ensuring that the earliest arrival times of the EDB Plume is estimated in this analysis. Thus, this 5-year infiltration time is added to all the estimates of groundwater flow times derived to yield the estimated arrival dates of EDB in the Hatchville area and, in turn, yield an estimate of the duration of potential exposure.

The distance from the closest potential source area, FS-2, to various locations within the Hatchville area is given in Table 1. Those distances, divided by the average groundwater flow velocity (1 ft/day) plus the 5-year infiltration time, yield the estimated arrival dates for the FS-28 Plume in the Hatchville area given in Table 2 and illustrated in Figure 7.

Table 1 - Approximate distances from potential source area FS-2.

Location	Distance (feet)
Monitoring well 1206z	5,000
Route 151	5,200
Coonamessett Water Supply Well (CWSW)	10,650

Hatchville Road	12,700
Upwelling groundwater zone	13,750
FS-28 Plume limit	15,296

Table 2 - Estimated arrival dates for FS-28 Plume in the Hatchville area.

Location	Infiltration and Migration Time (years)*	Plume Arrival Dates**
Monitoring well 1206z	18.7	1959 - 1964

Route 151	19	1959 - 1964
Coonamessett Water Supply Well (CWSW) area	34	1974 - 1979
Hatchville Road	40	1980 -1985
Upwelling groundwater zone	43	1983 -1988
FS-28 Plume limit	47	1987 - 1992

* The time estimates includes a 5-year period for infiltration of EDB from the FS-2 source area through the vadose zone to the water table. This 5-year infiltration time is estimated for an infiltration depth of 10 feet. Greater depths to the water table would increase the infiltration time and, therefore, decrease the length of potential exposure. The plume migration rate is approximated at 1-foot per day with no significant retardation of EDB.

** The Plume arrival dates given are base upon a release of EDB from the FS-2 source area during 1940-1945.

From 1996 to 1999, upwelling of the FS-28 Plume delivered EDB to the Coonamessett River and adjacent cranberry bogs in concentrations ranging from below the detection limit (0.0035 ppb) to as much as 0.73 ppb. The highest concentration of EDB measured in groundwater just below the surface of the watertable in the area of upwelling was 3.9 ppb (AFCEE, 1999a). Before start-up of the extraction well, the highest concentrations of EDB measured in the plume (16-18 ppb) were found deep within the core of the plume and about 200 ft below the surface of the watertable. This core of the highest concentrations of EDB was found in a sequence of silty sands and silty clays which may have retarded further migration.

It can be inferred from the configuration of the southward-migrating plume depicted in Figure 6, prior to 1983 to 1988 groundwater discharged to the river and bogs was uncontaminated. With the arrival of the leading-edge of the plume EDB levels rose from zero to those levels detected from 1996 to 1998. If extraction and treatment of the core of the plume had not occurred, the EDB levels measure in surface water would have continued to increase. Thus, the EDB levels measured during the 1996 - 1998 interval were probably the highest concentrations of EDB discharged to the river and bogs.

The GeoHydro Probabilistic Model

The second approach to estimating the early arrival date and EDB concentration in the Hatchville area is based upon the groundwater modeling effort sponsored by ATSDR and undertaken by GeoHydro (1998). The approach differs from the first approach by the weight or significance attributed to hydrogeologic variables and parameters. The one- and two-dimensional site-specific modeling of the FS-28 Plume migration was completed by GeoHydro using the ACTS software. The analytic models used in this tool are available in the public domain literature and are referenced throughout the GeoHydro draft report.

The uncertainties introduced into this two-dimensional model by the variations in hydrogeologic factors such as anisotropy and the effects of advection, dispersion, retardation, and decay (half-life) of the contaminant were evaluated using Monte Carlo methods to derive computational solutions at different levels of probable certainty. However, the model, assumes a constant groundwater velocity field. The model also attempts to integrate an evaluation of different values for the duration and magnitude of EDB concentrations at the spill or release site. Those spill scenarios given in the GeoHydro (1998) report assume a 1935 starting date but, in light of the more probable initial spill or release period being sometime in the 1940-1945 interval, ATSDR adjusted the model results to those starting dates.

The GeoHydro (1998) estimates of infiltration rate and time for precipitation and EDB to migrated down through the vadose zone were discussed in the previous section. The 5-year infiltration time calculated by the one-dimensional Marino Model are added to the saturated

groundwater flowpath time values obtained from 5000 Monte Carlo simulations of pore velocity, EDB half-life, retardation, and longitudinal and transverse dispersion coefficients. For a thorough discussion of the specific assumptions and computational manipulations involved in this modeling effort, the reader is referred to chapters 2 - 4 of the GeoHydro (1998) report.

The results of the GeoHydro modeling indicate that, if the FS-2 area is a potential source area at the initial EDB source concentrations previously discussed, there is, for example, a 5 percent probability for the leading-edge of the FS-28 EDB plume to reach the general vicinity of the Coonamessett Water Supply Well (CWSW) at a concentration of 0.02 - 0.14 ppb EDB within a total travel time of 22 years. The total travel time is comprised of 5-year infiltration period and a 17-year travel time in the saturated zone. The complementary cumulative probability distribution determined in this analysis is an indicator of the probability that a certain concentration may be exceeded at a certain point in time and space.

The estimated plume arrival dates at various locations in the Hatchville area for 5 and 20 percent is given in Table 3 and illustrated in Figure 8. This table illustrates that, given the range of the hydrogeologic variables considered in these simulations, there is a 5 percent probability for an EDB plume originating at FS-2 to reach the CWSW area by 1962 -1967 at a concentration level of 0.02 - 0.14 ppb. If we increase our confidence level to 20 percent, then the EDB arrival date at the CWSW area must be more recent (1972 - 1977), for the same concentration range. It follows that increasing the confidence level yields progressively more recent predicted plume arrival dates.

Table 3 - Probability estimates of the arrival dates for the FS-28 Plume in the Hatchville area.

Location	Estimated Plume Arrival Dates* Complementary Cumulative Probability Value**	
	5%	20%
Coonamessett Water Supply Well (CWSW) area	1962 - 1967	1972 - 1977
Hatchville Road	1969 - 1974	1983 -1988
FS-28 Plume limit	1978 - 1982	1991 - 1996

* Estimated arrival dates based upon release of EDB from the FS-2 source area during 1940-1945 and a 5-year period for infiltration.

** Based upon the results of 5000 Monte Carlo simulations of the hydrogeologic and chemical parameters for the concentration range of 0.02 - 0.14ppb EDB at the 5% and 20% probability levels.

Although GeoHydro did not compute plume arrival information for the upwelling groundwater

zone along the Coonamessett River, their data can be interpolated to estimate an arrival date of approximately 1986 to 1991 at the 20 percent probability level.

Comparison of Groundwater Plume Arrival Estimates

Inspection of the plume arrival dates given in Tables 2 and 3 shows general agreement between the dates determined using an average 1 ft/day groundwater flow velocity and those derived by GeoHydro at the 20 percent confidence level. Agreement between the two estimates at the 5 percent confidence level would necessitate an average groundwater flow velocity of about 1.33 ft/day; a rate within the upper end of the flow velocities associated with these outwash deposits. However, because a minimum value for the infiltration time (5 years) was used in these computations, the plume arrival times derived from a 1 ft/day average flow velocity (Table 2) and the 20 percent confidence level (Table 3) are probably closer estimates of the true plume arrival dates.

For these reasons, and in the absence of earlier monitoring data, ATSDR concludes that **from 1983 to mid-1999 (16 years) the FS-28 Plume discharged EDB to surface waters.** Thus, a 16-year interval of potential human exposure to EDB in surface water and air in the vicinity of the upwelling groundwater zone (see Fig. 4) is delineated and will be used in this consultation in the evaluation of those potential pathways of human exposure. **This is a conservative estimate of potential human exposure to EDB and, for the reasons given above, probably over-estimates the actual duration and level of potential exposure.**

$ Surface Water Contamination

Fate and Transport

As noted above, the contaminant plume at MMR discharges to the surface, releasing groundwater into the Coonamessett River. EDB does not persist for long durations in surface water bodies. Some experiments show that the half-life for EDB in flowing or standing surface water ranges between 1 and 16 days (ATSDR, 1992). Other experiments suggest that the half-life is longer (i.e., 4 weeks to 6 months;AFCEE, 1999a). Many of the physical processes (i.e., molecular diffusion and turbulent flow) and degradation processes (i.e., biodegradation and hydrolysis) discussed above play a role in removing EDB from surface water bodies. In addition, another degradation process—photolysis—also plays a role (GeoHydro, 1998). This process involves using energy from sunlight to break the bonds that hold a contaminant together. While all of these physical and degradation processes play a role in removing EDB from surface water, volatilization plays a much more prominent role. As discussed previously, EDB has a Henry' Law Constant in the 10^{-4} range; therefore, the chemical volatilizes into the atmosphere at a moderate rate. Because EDB disappears from surface water bodies so quickly, the chemical does

not tend to impact sediments that are present in the water body (ATSDR, 1992).

The Coonamessett River is diverted through several cranberry bogs. EDB is not expected to bioconcentrate in terrestrial or aquatic food chains, however, because the contaminant is so water soluble (ATSDR, 1992).

Hatchville Area Surface Water Contamination

EDB is the only organic contaminant detected in the surface waters of the Hatchville area. The FS-28 EDB Plume discharges to the surface in and near the lower Baptiste Bogs (see Figs. 4, 6, and 9) in a zone estimated to be about 300 feet wide and about 1200 feet long (AFCEE, 1999a,b). EDB is detected in the Coonamessett and Broad Rivers and in the irrigation ditches that surround the developed cranberry bogs. EDB has not been detected in the Coonamessett River upstream of the confluence with the Broad River. Concentrations decline rapidly in the downstream direction and have not been detectable as far south as the Route 28 river crossing. Data presented by AFCEE (1999a) illustrates this decline of EDB in the river from a maximum of 0.087 ppb adjacent to the midpoint of the Baptiste Bogs to a maximum of 0.0094 ppb adjacent to the midpoint of the Middle Bogs (see Fig. 9).

The highest EDB detections have been from samples collected in the ditch system servicing these developed cranberry bogs. Those detections also decline in a downgradient direction and range from the maximum surface water detection recorded (0.73 ppb) from a ditch on the west side of the Baptiste Bogs to 0.187 ppb at the southern end of that bog.

It is postulated that the higher detections of EDB are recorded in samples collected from the ditches because the volume of surface water flow in the ditches does not dilute the groundwater discharges as greatly as does the greater volume of flow of the Coonamessett River. Once entrained in surface waters, the EDB levels decline downgradient because of the combined effects of dilution and volatilization. However, the contaminant half-life evaluation and transport modeling efforts of GeoHydro (1998) suggest that little if any degradation occurs as the EDB is transported downstream.

Although the maximum surface water detection of EDB is 0.73 ppb, samples collected at surface water monitoring stations from 1996 through 1999 indicate that average EDB detection levels, depending on location (and the value assigned to the not detected [ND] samples), appear to range from about 0.01 to 0.06 ppb. GeoHydro (1998) estimated the EDB concentration in the river, based upon their derived groundwater concentration of 0.14 ppb and an average river discharge of 9.9 cubic feet per second (cfs), and obtained an average river concentration of 0.08 ppb EDB, which is in general agreement with the observed values.

Significant differences in discharge occur along the course of the Coonamessett River from Coonamessett Pond to Route 28. At the surface water gaging station just below Hatchville Road (69SW006) seasonal variation in discharge results in flows ranging from 0.58 to 6.29 cfs, while downstream, just above Thomas B. Landers Road the gaging station (69SW0046) records flow

ranging from 1.55 to 14.83 cfs (AFCEE, 1999a). It is in this gaining reach that the EDB is upwelling to the river. It is also in this region that the developed cranberry bogs are occasionally flooded, which increases the hydrostatic pressure which, in turn, tends to retard upwelling of the EDB groundwater plume. Further downstream, near Sandwich Road, mean flow has increased an additional 4.2 cfs, yielding further dilution of the EDB-load of the river.
Because of the combined effects of the EDB extraction well, treatment, and the discharge system, EDB has not been detected in the surface water environment since mid-1999. The monitoring data, modeling, and information compiled on the levels and location of EDB in the area's surface water environment lead ATSDR to the conclusion that **the segment of the Coonamessett River and adjacent cranberry bogs located between the Hatchville and Thomas B. Landers Roads comprise the only segment of that surface water environment that was, from possibly as early as 1983 to mid-1999, a potential (past) pathway of human exposure to EDB.**

Our understanding of the character of the FS-28 Plume and its interaction with surface waters suggests that the level of EDB discharged to the surface was certainly no greater than the levels detected in surface water after 1996. As noted, the observed EDB levels are similar to, but greater than those levels predicted by GeoHydro (1998). Lacking other evidence, ATSDR concludes that **from 1983 to mid-1999 (16 years) the FS-28 Plume discharged EDB to surface waters resulting in maximum observed concentrations of 0.73 ppb or less**[2]. However, average concentrations observed in the 1996 - 1999 interval in the network of bogs, ditches, and river in this area have ranged more on the order of 0.01 to 0.06 ppb EDB.

Potential cranberry contamination

Although not a focus of this consultation, recent research published by Xia and Rice (1999) concludes that EDB is loosely adhered to the waxy cuticle layer of the cranberry fruit rather than being absorbed by the flesh of the fruit. The amount of EDB associated with the cranberries was affected by the exposure level, time of exposure, and temperature. At temperatures that would be expected during harvest (10 - 20°C), the amount of EDB associated with the fruit, with EDB concentrations (up to 6 ppb) or exposure times (up to 7 days), did not change significantly. The lowest concentration associated with unwashed cranberries was 0.04 ppb when exposed to 3 ppb EDB in water and the higher was 0.15 ppb when exposed to 12 ppb EDB in water. Interestingly, the level of EDB associated with the fruit was less when the skin of the fruit was damaged or when the fruit was washed with deionized water. A rinse of cranberry fruit with deionized water after exposure to a 12 ppb EDB solution removed 64 to 75 percent of the associated EDB. The highest residual EDB concentration associated with the fruit after washing was 0.06 ppb at 10 - 20°C.

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[2] As has been previously noted, the maximum detected concentrations (0.73 ppb) were measured in the irrigations ditches on the bog periphery. EDB concentrations measured in the river were an order of magnitude less.

Given that the cranberries in the Xia and Rice (1999) research were subjected to levels of EDB exposure that exceed those measured or predicted in the surface waters and bogs of the Hatchville - Coonamessett River area; that the levels of EDB found to be associated with rinsed and un-rinsed cranberries are far less than the allowable 150 ppb for foods that need to be cooked before eating; and that 99 percent of the cranberries harvested in Massachusetts are harvested by the wet-pick method that results in the marketing of those berries as sauce, juice, jams, or jellies, we conclude that, **in the past and present, and foreseeable future, consumption of the local cranberry crop would not result in adverse human health effects.**

$ Air Contamination and Modeling

Fate and Transport

As noted above, much of the EDB that is present in surface water bodies volatilizes into the surrounding atmosphere. After volatilizing into the air, the chemical can be transported for long distances before degrading via reactions with hydroxyl radicals (ATSDR, 1992). Because of dispersion into the atmosphere, concentrations of EDB decline rapidly with increasing distance from the source. The half-life for EDB in the air has been reported to be about 40 days (ATSDR, 1992).

EDB in the Ambient Air of the Hatchville area

Since EDB was detected in surface waters of the Coonamessett River in the Hatchville area and because EDB can volatilize from those waters, there has been a concern about the potential for inhalation of EDB in the ambient air. Because the cranberry growers flood their bogs for harvest and in the winter for protection of the cranberry plants, there has been concern that the increased surface area flooded would increase the area from which volatilization of EDB could occur. To the extent that during most winters the ponds are frozen or the water temperatures very low, the volatilization of EDB from the water would be reduced at that time. Accordingly, flooding the bogs in the spring for insect protection or in the fall for harvest may temporarily increase the potential for EDB volatilization but, flooding the bogs may also have an opposite effect by increasing the hydrostatic pressure impeding discharge of the FS-28 Plume to the surface.

Massachusetts Department of Public Health Estimates

When concerns first arose about the potential for human exposure to EDB in the air, Jacobs Engineering, at the direction of AFCEE, prepared an assessment of the public health risk that may be associated with the winter flooding of the bogs. The Massachusetts Department of Public Health (MDPH, 1997) reviewed that assessment and concluded that flooding of the bogs from early winter through early spring of the year (1996 - 1997) would not present a public health concern from recreational public use of the area. To more fully respond to community concerns

regarding EDB volatilization from the cranberry bogs and the river, MDPH initiated a comprehensive four-step review and prepared a report (MDPH, 1997). First, MDPH reviewed the available data on EDB concentrations in the Hatchville area surface waters. Second, volatilization and air dispersion models were applied to estimate the highest possible EDB concentrations in ambient air under different conditions. Third, the predicted air concentrations were compared against relevant health-based screening values and, finally, conclusions and recommendations were drawn.

The MDPH researchers found that the maximum time a bog would be flooded with water from the river (assuming a wet harvest, winter flooding, and a spring flood) would be 120 days per year (17 weeks). Further, MDPH documented that water wells are used, depending upon levels of precipitation and weather conditions, to supply water to sprinkler irrigation systems for the cranberry crops.

Using maximum (0.36 ppb) and a detection level (0.005 ppb) concentrations of EDB in surface waters, MDPH applied recognized mathematical models to estimate EDB volatilization from: (1) sprinkler irrigation, (2) flooded bogs (assuming both constant recharge and no recharge of EDB-contaminated water) and the river system, and (3) air dispersion from the bogs and river under different meteorologic conditions. Table 4 summarizes the MDPH (1997) **maximum** predicted air concentrations of EDB downwind of major bogs and surface water areas of this Coonamessett River - Hatchville area. The "downwind" condition was modeled as a constant wind speed of 5 meters per second (11.2 mph); reasonably still atmospheric conditions with minimum dispersion.

Because the various models considered by MDPH in their study would inherently generate values that underestimate or overestimate the true air concentration level of EDB in this setting, MDPH selected the models and values that would generate a conservative (maximum) estimate. Although the maximum surface water concentration of EDB (0.36 ppb) evaluated in the MDPH study is lower than the maximum levels subsequently detected in irrigation ditches (0.73 ppb), it is much higher than the EDB levels detected at most surface water locations.

Examination of the data given in Table 4 discloses that predicted air concentrations are higher downwind from the bogs or reservoirs and lower downwind from the river. MDPH (1997) suggested that the true EDB air concentration value for the bogs probably lies in-between the values predicted by the constant-recharge and no-recharge models. In addition, the maximum predicted levels (constant-recharge model) are based upon a supply of 0.36 ppb EDB regardless of the location of the bog in relation to the zone of upwelling groundwater; the source of the highest, undiluted concentration of EDB in the surface water environment. The surface water monitoring data collected thus far (AFCEE, 1999a) show that the highest EDB levels in the river and bogs between the Hatchville and Thomas Landers Roads and progressively lower levels EDB are detected downstream (see Fig 9). Thus, there is no data or information to support the delivery of water containing as much as 0.36 ppb EDB to the bogs and reservoirs or ponds lying south (downstream) of the Thomas Landers Road crossing of the Coonamessett River. Accordingly, the

Table 4 - Maximum predicted air concentrations of EDB downwind from cranberry bogs and the Coonamessett River in the Hatchville area.

Location	Surface Area (acres or width)	Scenario[3]	Max predicted EDB level in air[4]		ATSDR Health-Based Screening Value (ppb) CREG[5]
			No-Recharge Model (ppb)	Constant-Recharge Model (ppb)	
Bogs between Hatchville and Thomas Landers Roads	17.3 ac.	Maximum-level	0.028	0.069	0.005
		Detection-limit	0.00001	0.0006	

[3] Maximum-level scenario: Surface water EDB concentration 0.36 ppb
Detection-limit scenario: Surface water EDB equal to the method detection limit (0.005 ppb)

[4] Predicted EDB concentration for a location 100 meters directly downwind of the emission source.

[5] CREG - Cancer Risk Evaluation Guides are estimated concentrations in water, soil, or air that would be expected to cause no more than one excess cancer in a million persons exposed over a 70-year lifetime (see Appendix A).

Bogs between Thomas Landers and Sandwich Roads	4.6 ac.	Maximum-level	0.0073	0.018	0.005
		Detection-limit	0.000005	0.0002	
Bogs below Sandwich Road	32.2 ac.	Maximum-level	0.051	0.129	0.005
		Detection-limit	0.00003	0.001	
Broad River (reservoir)	1.3 ac.	Maximum-level	0.0001	0.0097	0.005
		Detection-limit	0.000002	0.0001	

Coonamessett River	3 m. width	Maximum-level	NA	0.0002	0.005
		Detection-limit	NA	0.000003	

After MDPH, 1997

maximum predicted EDB values given in Table 4 for the bogs that lie at progressively greater distances downstream from the FS-28 Plume upwelling zone are higher than the true values for those areas.

Jacobs Engineering - AFCEE Sampling

To further evaluate the potential for human exposure to EDB in the potential air pathway described by MDPH (1997) and to respond to recommendations made by that report, Jacobs Engineering, at the direction of AFCEE, collected coordinated surface water and air sampling within and peripheral to the zone of EDB upwelling in the Coonamessett River area. A location spanning the confluence of the Coonamessett and Broad Rivers was selected for air monitoring because the highest concentrations of EDB were detected in surface water samples from this location. Broad River has a relatively large surface area and thus the highest potential for release of EDB to the air.

Three, 8-hour air samples were collected during each sampling event; one about 300 feet upwind, one at the water surface, and one 300 feet downwind. Those sampling locations were situated in a southwest - northeast orientation to approximate the prevailing wind conditions at the site. Surface water samples were also collected during each sampling event adjacent to the air sampling location at the water surface. A total of six sampling events took place in 1997: (1) May 29 - to evaluate the feasibility of the study design, then weekly on (2) July 17, (3) July 24, (4) July 31, and biweekly on (5) August 14 and (6) August 27. The results obtained from those sampling events are given in Table 5.

As part of the customary quality control and assurance procedures, analyses were conducted on the trip, method, and canister blanks. Although the analyses did not disclose EDB in the trip and method blanks associated with these field sampling events, analysis of the canister blanks (canisters used to verify the quality of the lot of canisters) for the first two July sampling events detected very low levels of EDB and thus, the sample results for those dates may be biased to high levels due to the low background levels in the canisters (AFCEE, 1999a).

Examination of the data given in Table 5 discloses that the highest EDB value detected (0.01 ppb) was obtained from samples collected from the air immediately above the river surface. The highest value collected 300 feet downwind was 0.007 ppb (also from a canister lot potentially biased to high levels). Other upwind and downwind samples range from 0.001 to 0.005 ppb.

Comparison of MDPH Modeling Results and Jacobs Engineering Sampling Results

Generally, the Jacobs Engineering (AFCEE, 1999a) sampling results are an order magnitude less than the maximum, downwind values MDPH (1997) predicted for the bogs between the Hatchville and Thomas Landers Roads (see Tables 4 and 5). While the maximum surface water concentrations of EDB measured during the air sampling events was slightly less than the MDPH modeling concentration (0.25 ppb vs. 0.36 ppb) the meteorological conditions at the time of

sampling were general similar. The values obtained at the water surface locations were obtained just a few inches above the water, not at a breathing-zone height, and thus, represent levels higher than would be inhaled at that time the sample was collected.

As previously noted, the MDPH analysis was formulated using conservative assumptions to derive a maximum predicted air concentration. Given that the AFCEE (1999a) field sampling conditions were generally comparable to those modeled by MDPH, **the field sampling data obtained indicates that the maximum-level values obtained by MDPH overestimate the true ambient air levels.** In their report MDPH (1997) acknowledges that the true EDB air concentration probably lies between the maximum-level, constant-recharge scenario and the minimum-level scenario.

Although it is reasonable to expect downwind ambient air concentrations to be higher than upwind locations, the AFCEE (1999) data do not show that effect at the low-wind conditions which prevailed during sampling events. At greater wind velocities, dispersion of the airborne EDB would be greater and thus, the available sampling data given in Table 5 appears to describe the maximum potential human exposure to EDB in the air in the Hatchville area.

As previously discussed in this Consultation, the data and information amassed on the character of the FS-28 Plume and its interaction with surface waters supports a conclusion that the level of EDB discharged to the surface has probably never exceeded the levels detected in surface water since 1996. Thus, the EDB air sampling conducted by Jacobs Engineering (AFCEE, 1999a) is probably representative of the maximum levels of EDB in ambient air during the 1983 - 1999 interval.

Based upon the soundness of the analytical methods used by Jacobs Engineering, ATSDR concludes that the maximum level of EDB in the air is not likely to have exceeded 0.01 ppb (CREG 0.005 ppb) at locations over the Baptiste Bogs and adjacent Coonamessette and Broad Rivers (see Fig. 9). At nearby locations within about 300 feet of the river or flooded bogs our evaluation of the modeling and sampling results leads us to the conclusion that **the maximum levels of airborne EDB probably did not exceed 0.01 ppb throughout the potential human exposure period from 1983 to mid-1999**. Because of dispersion, it is likely that upwind and downwind locations did not experience airborne EDB levels greater than about 0.005 ppb throughout the 16-year potential past exposure interval.

Table 5 - Broad River air and surface water sampling.

Date	Wind (mph)	Temp. (F)	EDB in surface water (ppb)	Air sampling location	EDB in air (ppb) [6, 7]
05/27/97	10	60s	0.11	Upwind	0.001U
				River	0.002U
				Downwind	0.002U
07/17/97	5-15	80s	0.25	Upwind	0.005
				River	0.007
				Downwind	0.007
07/24/97	10	Hi 60s - Mid 70s	0.053	Upwind	0.004
				River	**0.01 (79.0 ng/m3)**
				Downwind	0.001U
07/31/97	1-6	80s	0.14	Upwind	0.001U
				River	0.003
				Downwind	0.001U
08/14/97	1-4	70s - Mid 80s	0.12	Upwind	0.003
				River	0.007
				Downwind	0.002
08/27/97	1-4	Mid 60s - 70s	0.14	Upwind	0.002
				River	0.002
				Downwind	0.001

After AFCEE, 1999a

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[6] Reporting limit = 0.001 ppb

[7] Undetected result = U

Evaluation of Potential Pathways of Human Exposure

$ Introduction

In this section, ATSDR evaluates environmental data to determine whether contamination poses hazards to people having access to or living near the Coonamessett River - Hatchville area. ATSDR's public health evaluations are driven by exposure to (contact with) contaminated media. In evaluating exposure pathways, ATSDR determines whether exposure to contaminated media has occurred, is occurring, or will occur through ingestion, dermal (skin) contact, or inhalation of contaminants. To determine whether environmental pathways of human exposure pose a potential health hazard, ATSDR compares contaminant concentrations to health-based comparison values (CVs). CVs are calculated by ATSDR toxicologists, using available scientific literature on exposure and health effects. These values, which are derived for each of the different media, reflect the estimated contaminant concentration for a given chemical that is not likely to cause health effects, given a standard body weight and a standard daily ingestion rate for a specified period. Contaminants detected above the CVs do not automatically present a public health hazard. If contaminant concentrations are above CVs, ATSDR further analyzes exposure and the toxicology of the contaminant to determine whether a public health hazard could occur.

The potential pathways of human exposure to EDB in the Hatchville area are summarized in Figure 6. The available CVs for EDB in water and air are given in Table 7 (see also Appendix B).

$ Groundwater Pathway

The data gathered during the preparation of the Southwest Operable Unit RI and related documents (see AFCEE, 1999a, 1999b) show **no evidence that private and municipal drinking water wells have been or are likely to be contaminated by EDB in the FS-28 Plume.**

In addition, AFCEE has replaced many private drinking water wells with municipal water that is subject to periodic monitoring to ensure its safety. The Coonamessett Water Supply Well is equipped with a granular activated-carbon filtration system to further ensure that water supplied by that well is safe to drink.

ATSDR **concludes that, in the Hatchville area, there is no past, present, or potential future pathway of human exposure to EDB-contaminated drinking water** from private or municipal drinking water wells.

Table 6 - Potential Past Exposure Pathways.

Pathway Name	Compounds	Exposure Pathway Elements					Time
		Source	Media	Point of Exposure	Route of Exposure	Potentially Exposed Population	
Surface water - Coonamessett River, Broad River, and bog ditches between Hatchville and Thomas Landers Roads (Zone 1)	EDB	FS-28 EDB Plume - downstream from the zone of upwelling groundwater	Surface water	Coonamessett River, Broad River, bog irrigation ditches, and ponds	Incidental ingestion and dermal exposure	Cranberry bog workers, Recreational users or area. (150-200 people)	PAST (1983 - mid-1999)
Surface water - Coonamessett River and adjacent bogs between Thomas Landers Road and Route 28 (Zone 2)	EDB	FS-28 EDB Plume - same as above	Surface water	River, bogs, and ponds downstream from Thomas Landers Road	Incidental ingestion and dermal exposure	Cranberry bog workers, Recreational users of area	PAST (1983 - mid-1999)
Air - Zone 1	EDB	Volatilization from surface waters of Coonamessett & Broad Rivers, cranberry bog and ditches	Ambient air	Air within 300 feet of surface waters in this zone	Inhalation	Cranberry bog workers, Recreational users and any residents within 300 feet of surface water	PAST (1983 - mid-1999)
Air - Zone 2	EDB	Volatilization from surface waters of Coonamessett River, bogs, ponds, & ditches	Ambient air	Air within 300 feet of this zone	Inhalation	Same as above	PAST (1983 - mid-1999)

Table 7 - EDB comparison values and health-based screening values[8].

Media	MCL (ppb)	CREG (ppb)	Cancer Slope Factor $(mg/kg/day)^{-1}$
Water	0.05 (EPA) 0.02 (Mass.)	0.0004	85
Air	Not Applicable	0.005	0.00022

Surface Water and Air Pathways

The data presented in this public health consultation identifies two potential pathways of human exposure to EDB in the Hatchville area: a surface water pathway and an air pathway (see Table 6). The data developed also identifies the area within about 300 feet of the Coonamessett River and adjacent cranberry bogs between the Hatchville and Thomas B. Landers road crossings of the river as the geographic area of the greatest potential human exposure to EDB in those pathways. These potential pathways are summarized in Table 6.

To facilitate this public health evaluation, the areas of potential past human exposure have been divided into two zones: Zone 1 encompassing the area of greatest potential human exposure to EDB and Zone 2 comprising the downstream areas of lower potential exposure (see also the Fig. 9 location map).

Within Zones 1 and 2 the maximum duration of exposure is about 16 years (1983 to May 1999). Within Zone 1 the maximum level of EDB detected in surface water is 0.73 ppb. Although there is no monitoring data for EDB in surface water for the 1983 - 1996 interval, the results of modeling and the character and configuration of the FS-28 Plume do not suggest that historical levels were higher than those measured from 1996 - 1999. Using this information, there is no basis to suggest that ambient air levels of EDB ever exceeded 0.01 ppb.

Because the potential surface water and ambient air pathways are interrelated, they are discussed together in this section.

ATSDR determined, based upon current epidemiologic, toxicologic, and medical information, that the EDB contamination in surface water and air in the cranberry bog area is unlikely to have presented a health hazard to cranberry workers or nearby recreational users of the bog areas. The estimated exposure levels to workers from breathing EDB in air, from drinking or skin contact with contaminated surface water were lower than levels at which adverse health effects have been shown to occur. Other people in the vicinity of the bogs such as recreational users of the paths along the bogs would not be exposed to levels of EDB that would result in harmful health effects, even to more sensitive populations such as children.

In looking at whom might be exposed to EDB in surface water, ATSDR decided to focus its evaluation on workers harvesting cranberries and maintaining ditches along cranberry bogs. This group represented the most highly exposed individuals because the workers had the highest opportunity for contact with EDB contaminated water and air. These workers may be exposed to EDB from breathing this chemical as it evaporates from surface water, accidentally ingesting the water, and by skin contact with water in the bogs.

To be protective of public health, ATSDR made assumptions about how a worker would be exposed to EDB that represented a worst-case scenario for exposure. Those exposure assumptions were based upon the information developed in this consultation and a review of the workdays required to maintain the cranberry bogs and harvest the crop (AFCEE, 1999a). It was assumed a worker would be exposed 100% of the time (e.g., an 8-hour day, 12 days per year, 16 year duration) to the maximum detected concentration in air and surface water. Conservative assumptions were also made about the amount of air that a worker would breathe. Appendix C contains the exposure assumptions that were used in estimating exposures to workers in the bogs.

Breathing contaminated air contributed the majority of the exposure, with an additional small contribution to total exposure from ingesting contaminated surface water. ATSDR reviewed the contribution to total EDB exposure from skin contact with surface water and sediment in the bogs as detailed in the risk assessment report for the Southwest Operable Unit (SWOU) remedial investigation (AFCEE, 1999a). The contribution to total exposure was so small that no attempt was made to independently estimate this exposure value. Rather, we included this previously calculated value in the total combined exposure level for completeness.

The character of potential exposure of nearby residents and recreational users to EDB differs from the cranberry bog workers in the duration of uninterrupted time spent in the zone of maximum exposure. Due to numerous factors including proximity to the Coonamessett River valley, topographic separation above the valley floor, atmospheric dispersion of EDB, variable wind directions over time, and the micrometeorology of river valleys, it is unlikely that nearby residents have been exposed to levels and duration of exposure to EDB in the air that might result in adverse health effects. Because the time spent by recreationists in the zone of potentially highest exposure is less that the 8-hour interval spent by cranberry workers, it also follows that those individuals, including sensitive populations such as children, would not be exposed to levels of EDB that would result in adverse health effects. Further, it should be noted that the evaluation of workers included both inhalation and dermal exposure at maximum levels; the potential exposure to residents and recreational users is primarily, if not totally, inhalation exposure at lower duration and frequency than the cranberry workers.

Noncancer health effects of exposure

ATSDR determined that the levels of exposure to EDB were unlikely to produce adverse health effects in cranberry workers. The following section provides justification for ATSDR's conclusion about the likelihood of adverse health effects.

Humans are susceptible to acute (short-term) toxic effects of EDB. Except for adverse reproductive effects in men after inhalation exposure, chronic (long-term) effects of EDB exposure have not been documented. Although there is little information on the toxicity of EDB in humans after inhalation, the testis was a target organ in exposed workers, while the liver and kidneys have been identified as target organs after dermal (skin) and oral exposure in humans (ATSDR 1990). People taking the drug antabuse (disulfiram) are at an increased risk of adverse heath effects to the liver. There seems to be a potentiating effect on the toxicity of EDB from

[8] See Appendix A for definitions of comparison values and health-based screening values used.

interactions with disulfiram. Additionally, anyone with compromised liver function is also at an increased risk. The liver, kidney and testis are target organs in experimental animals independent of exposure route (ATSDR 1990).

Currently, no ATSDR minimal risk level exists for EDB because of a lack of quantitative exposure data. A provisional inhalation reference dose of 5.7×10^{-5} mg/kg/day is based upon impaired spermatogenesis in human males (EPA, 1997). This reference dose is an estimate of the daily exposure level for the human population, including sensitive subpopulations, that would be without adverse, noncancer health effects during a lifetime.

To examine whether long-term occupational exposure to EDB affects semen quality, a study was conducted among men employed in the papaya fumigation industry (Ratcliffe et al, 1987). The average duration of exposure was five years and the mean level of EDB in air was 88 ppb (8-hour, time-weighted average) with peak levels up to 262 ppb. The comparison group consisted of unexposed men from a nearby sugar refinery. Statistically significant decreases in ejaculate sperm count, the percentage of viable and motile sperm, and increases in the proportion of sperm with structural abnormalities were observed among exposed men by comparison with controls after consideration of smoking, caffeine and alcohol consumption, age, abstinence, history of urogenital disorders, and other potentially confounding variables. **The maximum level of EDB in air in the cranberry bogs was over 8000 times lower than the lowest level identified in the study by Ratcliffe et al.**

The American Conference of Governmental Industrial Hygienists (ACGIH) recommends a limit of 0.045 ppm (45 ppb) EDB in air (ACGIH, 1998). This is the level that ACGIH believes a healthy adult worker could be exposed to day after day without adverse health effects. **The maximum level detected in air at the cranberry bogs was 1.0×10^{-5} ppm, approximately 4,500 times lower.**

Based upon the assumptions given above and detailed in Appendix C, the worst-case, average daily exposure dose for a worker from breathing the maximum concentrations of EDB over the 16-year exposure period is estimated to be 9.8×10^{-7} mg/kg/day, and from all exposure routes combined at 1.06×10^{-6} mg/kg/day. **The total combined exposure estimates for the cranberry workers (9.8×10^{-7} mg/kg/day) was 58 times lower than the EPA provisional inhalation reference dose.**

The maximum concentration of EDB in the cranberry bog air, and the worst-case EDB exposure estimates for cranberry workers were both below these protective levels, indicating that harmful health effects from exposure are unlikely.

Cancer effects of exposure

When evaluating cancer effects from exposure, ATSDR's policy is to adopt a qualitative, weight-of-evidence approach, in making a determination regarding the likelihood of cancer (ATSDR, 1993). A range of data for EDB was evaluated, including epidemiologic studies, animal studies, laboratory bioassays, genetic biomarkers, and dose response modeling. ATSDR considers that **the levels of exposure to EDB for cranberry workers were below a level of concern for cancer effects, and that no potentially significant human health hazard exists from exposure to EDB in the cranberry bogs.** The following section provides the basis for ATSDR's determination.

In experimental animals exposed by the inhalation route, EDB is carcinogenic, producing tumors at the site of contact in the upper respiratory tract and other organ systems (ATSDR, 1990). The levels of EDB that these animals were exposed to were much higher than the levels in the cranberry bogs.

Laboratory assays with mammalian cell lines show that EDB acts as a potent mutagen on DNA. However, EDB did not induce mutations in rats exposed by inhalation to EDB vapor at exposure levels as high as 39 ppm (ATSDR, 1990). In a study conducted on workers involved in spraying EDB on fallen pine trees, the estimated average exposure level of EDB was 0.06 ppm (ATSDR, 1990). The rates of chromosomal aberrations measured in lymphocytes obtained from these workers soon after exposure were not higher than those observed in the same individuals before the exposures. The levels of EDB that these people were exposed to were higher than the levels in the cranberry bogs.

Two epidemiological studies have not identified an increased risk of cancer in people occupationally exposed by inhalation to EDB (Ott et al, 1980; Turner and Barry, 1979). These studies had several limitations, including not controlling for confounding factors such as smoking, incomplete identification of exposure levels of EDB, and exposure of workers to other chemicals and small sample size. Because of these limitations, these studies neither support nor refute the possibility that EDB is a human carcinogen.

For comparison purposes, ATSDR estimated a quantitative cancer risk for a worker exposed to the maximum concentrations of EDB across all routes of exposure. This was performed by applying a cancer potency factor (a statistical estimate of the upper-bound cancer risk at a particular dose level) to the lifetime average daily dose calculated with the assumptions in appendix C. The dose estimate of 2.52×10^{-7} mg/kg/day represents the lifetime average daily dose, where the dose over the 16-year exposure period is prorated over a 70-year lifetime.

An estimate of the theoretical increase in cancer risk was determined to be 2×10^{-6} (2 in a million cancer risk). Since this represents the upper bound range of the risk estimate, the true level of excess cancer risk is likely lower and may be as low as zero. Generally, regulatory agencies such as EPA consider small excess cancer risks at this level to not present a significant health hazard.

For additional discussion of the health effects associated with exposures to EDB the reader is directed to Appendix B. It must be noted that the potential exposure doses calculated for the Hatchville area are below those doses responsible for the health effects noted in human or in animal studies.

In summary, the levels of potential exposure to EDB in surface water and air evaluated in the Hatchville, MA area do not represent a human health threat for cranberry workers or the other community members that may recreate in or reside in or near the zone of potential exposure delineated in this report.

ATSDR Child Health Initiative

ATSDR's Child Health Initiative recognizes that the unique vulnerabilities of infants and children demand special emphasis in communities faced with contamination of their water, soil, air, or food. Children may be at greater risk than adults from certain kinds of hazardous substances emitted from waste sites and emergency events. This is so because of several factors. They may be more likely to be exposed because they play outdoors and they may bring food into contaminated areas. They are shorter than adults, which means they may breathe dust, soil, and heavy vapors close to the ground. Children are also smaller, resulting in higher doses of chemical exposure per unit of body weight. The developing body systems of children can sustain permanent damage if toxic exposures occur during critical growth stages. Most important, children depend completely on adults for risk identification and management decisions, housing decisions, and access to medical care. ATSDR considered the likelihood for children living near the Coonamessett River and adjacent cranberry bogs to be exposed to EDB at levels of health concern. Our evaluation of the combined EDB surface water and air pathways for an adult cranberry bog worker (the maximum exposed individual) indicated that no adverse health effects should be expected. **The potential exposure levels for children that may recreate in this area is assumed to be of shorter time, frequency, and duration**

than that evaluated for the cranberry workers. Because children have less opportunity for and intensity of EDB exposure, no special hazards to children were identified.

Conclusions

$ The FS-28 Plume of ethylene dibromide (EDB) contaminated groundwater has not contaminated private or municipal drinking water wells in the Hatchville, MA area and those wells do not represent a past, present, or potential future public health hazard.

$ EDB contamination in surface water and ambient air of the Hatchville area occurred from no earlier than about 1983 to May 1999. The highest potential for human exposure to EDB in surface water occurred in the Coonamessett River and adjacent cranberry bogs in the zone between the river crossings of the Hatchville and Thomas B. Landers Roads. The highest potential for EDB exposure in the air also occurred immediately above and in close proximity to the river and bogs in the same area.

$ A conservative analysis of the potential past exposure to EDB contamination in surface water and air of the cranberry bogs area, near the upwelling zone of the FS-28 Plume, shows that no adverse human health effects should arise from this low-level exposure to EDB. In downstream locations, below Thomas B. Landers Road, EDB contamination levels are progressively lower, and therefore, the potential for adverse human health effects is lower as well. Accordingly, there does not appear to be the need for follow-up health activities regarding EDB exposure in the Hatchville, MA area.

Recommendations and Public Health Action Plan

Because no adverse human health effects are expected to result from of past human exposure to the very low levels of EDB in the surface water and air of the Hatchville area, there is no need for follow-up health studies of workers or residents of this area. **However, it is recommended that the U.S. Air Force continue a program of treatment and environmental monitoring for EDB in the groundwater and surface waters to ensure that unexpected levels of EDB contamination do not occur.**

Completed and Ongoing Actions

$ The U.S. Air Force-sponsored investigations of the character and extent of environmental contamination at MMR and off-base locations. Those investigations have identified opportunities to mitigate or prevent human exposure to contaminants in groundwater, surface water, surface soils, and air.

$ The U.S. Air Force conducts periodic monitoring of contaminants in groundwater and surface water to ensure that the extent and nature of contamination is understood; to guard against potential future human or ecosystem exposure to contaminants; and to measure the effectiveness of remediation measures such as the deep extraction well and shallow well-points in the FS-28 Plume.

$ The U.S. Air Force has equipped the Coonamessett Water Supply Well with a granular activated-carbon filtration system and conducts routine monitoring of nearby monitoring wells to help ensure that the municipal supply is safe to drink.

$ The U.S. Air Force has tested private drinking water wells for EDB and even though EDB has not been detected in those wells the Air Force has provided about 128 municipal water supply connections to Hatchville area residences that previously relied on private water wells.

$ The Massachusetts Department of Public Health, in cooperation with the Agency for Toxic Substances and Disease Registry, maintains a public health oversight role for the remedial investigation and site- or media-specific cleanup activities that are implemented at or near MMR. Numerous public health consultations have been completed, as well as an evaluation of cancer in census tracts surrounding MMR.

$ The Agency for Toxic Substances and Disease Registry has completed a Public Health Assessment for the Otis Air National Guard Base/Camp Edwards (a.k.a. MMR) and has completed a follow-up study of human health of self-reported symptoms, illness, and biomedical tests of residents in fours communities near MMR.

$ The Agency for Toxic Substances and Disease Registry organized a community assistance panel (CAP) to facilitate communication with community residents and to help identify potential public health issues relating to MMR.

$ The Agency for Toxic Substances and Disease Registry sponsored a multi-pathway environmental exposure assessment to assist in the evaluation of potential human exposure to EDB in the FS-28 Plume. A draft of that report was received in August 1998.

Planned Future Actions

$ The U.S. Air Force plans to continue environmental monitoring activities and the operation of various cleanup systems, such as the deep extraction well in the FS-28 Plume, until such time as contaminant levels drop below levels of concern or specific remediation objectives have been met.

$ The Massachusetts Department of Public Health, in cooperation with the Agency for Toxic Substances and Disease Registry, will continue to monitor public health issues at MMR and nearby areas. The Department will proceed with plans to investigate lung cancer on Upper Cape Cod.

$ The Agency for Toxic Substances and Disease Registry will, as new data are developed regarding environmental contamination at the MMR, review those data and, as necessary, evaluate the potential public health effects that may arise.

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